NOVEL PERMANENT MAGNETS AND THEIR USES

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ABSTRACT

Two changes have gone hand-in-hand during the 20th century. First, applications were conceived that required new or greatly improved materials. Need being the mother of invention, materials were then developed to satisfy the applications. Permanent magnets are today used in devices that could only have been dreamed about 25 years ago. Who could have foreseen, for example, the advances in data storage that have occurred over the last 15 years? In 1984, hard disk drives of under 10 megabytes in size and with random access times of over 65 milliseconds were the norm. Today, the standard drive is well over 10 gigabytes, is smaller in size and costs less than a fourth of the old drives, with an access time of 10 milliseconds and more than 33 mbps burst throughput. "Novel" has two interpretations: it may refer to the magnetic material or it may refer to the application of a material. Several examples of each are presented.

INTRODUCTION

Until the late 1930's, permanent magnets were predominantly steel compositions with low energy product and coercivity. Rather than utilizing permanent magnets, loudspeakers used an interaction of electromagnetic fields and motors were of the induction type. The invention of alnico allowed product size reduction through the use of permanent magnets in place of induction coils.

Approximately every 12 years thereafter, a new magnetic material was discovered. Figure 1 shows how the maximum energy product has increased. It also illustrates that materials with lower energy product, specifically ferrite, can be commercially successful. Introduced in 1961, ferrite remains the largest selling permanent magnet material on a weight basis primarily because of its relatively low price.

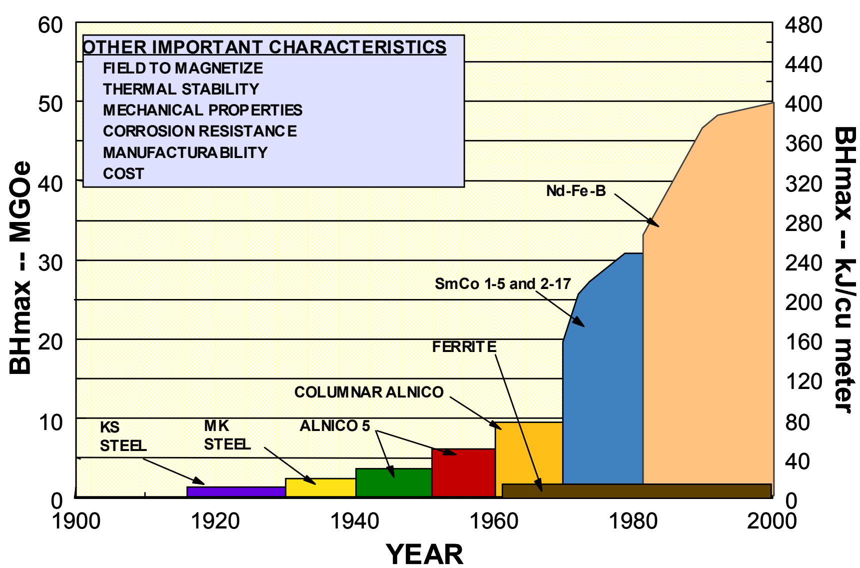

Figure I
Development of Permanent Magnet Materials

New materials have not obviated older ones: each has advantages and disadvantages. Alnico, though magnetically weaker than rare earth magnets, is much more temperature stable. Applications requiring stability over wide temperature ranges still rely on alnico. But the newer materials (ferrite, samarium cobalt, neodymium-iron-boron) all have a very important characteristic, a "square" second quadrant intrinsic curve, which allows use in applications which were not possible before.

NOVEL MATERIALS

The first question we must ask is: “What do we mean by novel?” It is proposed here that novel refers to a new magnetic material, a new application or design or a significant variation of an older design. To be considered, the material or application must also be commercially successful. Novel might also refer to the lack of general knowledge about a material or an application.

Table I is a summary of commercially available materials and processing methods. Prior to the announcement of SmFeN for use in bonded magnets, the newest material in the table was NdFeB, which is 15 years old. Old materials are not necessarily stagnant. Improvements in composition and processing of NdFeB powders for bonded magnets, for example, have raised the maximum recommended use temperature from 110°C to 180°C. Neodymium-iron-boron is no longer a novel material in that it was commercially introduced in November 1984. However, the melt-spun isotropic powder for bonded magnets was not readily available until the late 1980’s. Since it represented a new family of materials with new magnetic properties and limitations, applications had to be designed from scratch, a process requiring two to four years. The first products to take advantage of this new material were microelectronics produced in the Far East. Bonded neodymium-iron-boron magnets have become widely used in the United States only in approximately the last five years.

Table I
Commercially Available Permanent Magnet Materials

				BONDED			
MATERIAL	CAST	EXTRUDED OR ROLLED	SINTERED FULLY DENSE	INJECTION MOLDED	COMPRESSION BONDED	FLEXIBLE	RIGID EXTRUDED
ALNICO	Y		Y	Y			
IRON-CHROME-COBALT		Y					
CuNiFe		Y					
SmCo			Y	Y	Y		
SmFe(N,C)				Y			
NdFeB			Y	Y	Y	Y	Y
FERRITE			Y	Y		Y	
HYBRIDS				Y	Y	Y	

Bonded magnets represent a diverse set of capabilities and properties. Figure 2 shows the combinations of materials, binders and forming processes. The low processing temperatures allow mixing of heterogeneous materials within the binding matrix. Several combinations have been proposed or tried since the early 1970’s including ferrite with samarium cobalt or ferrite with neodymium-iron-boron. Different grades of a single material family can also be mixed to achieve new properties, though with only an averaging effect. The advantage of ferrite over either of the rare earth compositions is that the ferrite has a

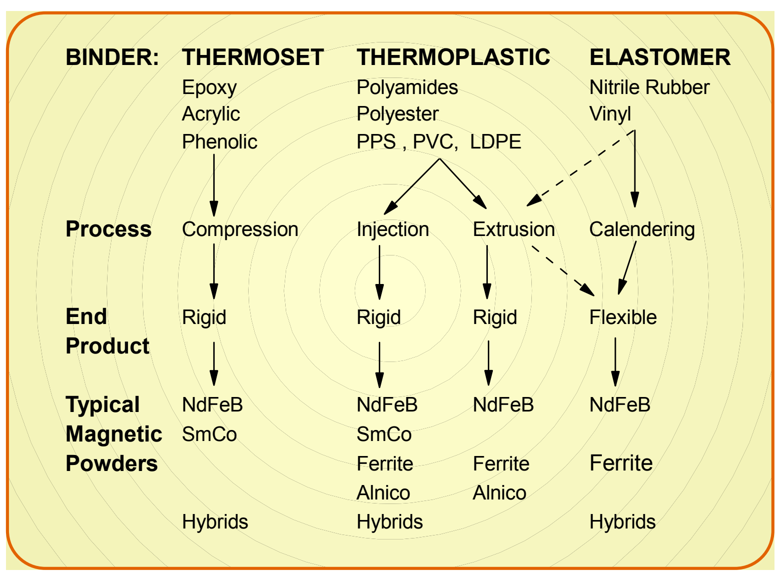

Figure 2
Diversity of Bonded Magnets

positive temperature coefficient of coercivity while that of the rare earths is negative. There is a synergy in performance and in price.

Another material is being prepared for commercial introduction: samarium-iron-nitride. Asahi Corporation received U.S. patents in 1987 for the material and processing method. Siemens, Hitachi and Sumitomo have all done extensive research on manufacturing SmFeN. Making the material has been challenging: when the nitride gas is forced into the crystal lattice of the samarium-iron base alloy, the alloy tends to decompose into samarium-nitride and alpha-iron. The nitrogen is interstitial, so it may be ejected from its position in the lattice causing decomposition. This is hastened when the temperature rises. Above about 450°C, decomposition is rapid. The claimed advantages include improved corrosion resistance over neodymium-iron-boron and improved temperature stability.

Developments have also taken place in rolled alloys. These are malleable alloy compositions rolled in continuous strips of thin foils. Recently introduced materials are "semi-hard" with coercivity ranging from 20 to 100 oersteds. The primary use for these alloys is in EAS (electronic article surveillance or anti-theft tags).

NOVEL APPLICATIONS

With so little new in materials, we will focus on applications. Hard disk drives are sold by the tens of millions each year. Who here does not have at least one? What is novel, I propose, is the extent to which the technology has progressed: magnets have increased in energy output, the magnet voice coil assemblies have become smaller in size and the drives have gone from 8" (width form factor) to 3.5 inches. Portable computers use 2.5" drives. IBM has introduced an even smaller drive (smaller than a pack of cigarettes). Several years ago, Ted Davis, President of Ted Davis Manufacturing (now part of Vacuumschmelze), complimented the industry on advances in the permanent magnets used in drives and the miniaturization that new materials allowed. He went on to challenge the industry to improve the flux carrying ability of the soft magnetic components so their size could also be reduced. Figure 4 shows example components. Notice the relative thickness of the magnet and the steel to which it is mounted.

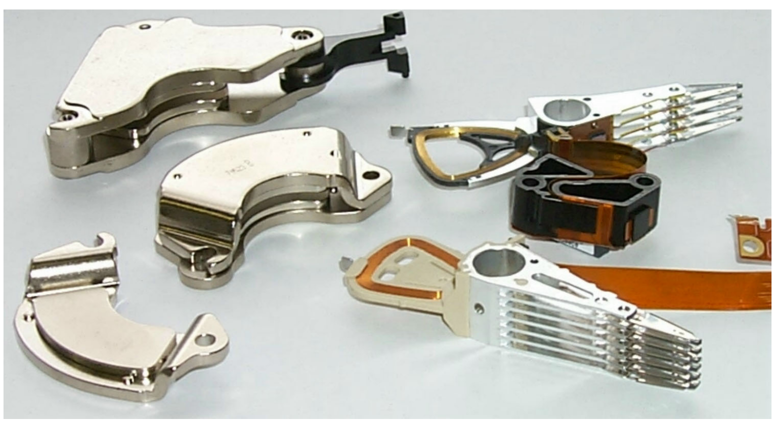

Figure 4
Hard Disk Drive Components
Items on the left are nickel plated NdFeB magnets and steel return paths; items on the right are the read/write head assemblies. All items are courtesy of Western Digital Corporation.

Voice coil motors in hard drives are either rotary, such as in Figure 4, or linear. The concept is a variation on a loudspeaker assembly wherein an electromagnetic field interacts with the field from a permanent magnet to produce motion. Another device using this principle is the "air core" gauge. These usually consist of two coils of wire, perpendicular to each other, with a disk shaped magnet inside. The field produced by the coils of wire is dependent upon the relative current in each coil. The diametrally magnetized, internally located magnet, rotates to align with the electromagnetic field. Two such gauges are shown in Figure 5 with magnets used in the gauge shown in front. The staff protruding from the gauge will have a pointer pressed onto the end. These gauges are used in cars, boats, trains, trucks, and more. The annual consumption of gauges in the western world is in excess of 100 million. Additional magnet examples are shown in Figure 6 and include oriented and unoriented injection molded ferrite, injection molded neodymium-iron-boron, sintered neodymium-iron-boron, sintered alnico and iron-chrome-cobalt.

What is unique about this gauge construction is that the coil is stationary and the magnet moves. Early gauge design used a stationary magnet and a moving coil, just as in the hard disk drive example given above. The can around the gauge is to provide magnetic shielding both from without and from within. Coincidentally, it also imparts some hysteresis to movement of the magnet, reducing vibration of the gauge pointer.

Hysteresis coupling can be used advantageously such as in drive devices with limited travel. Examples are electric window motors. When the window reaches end-of-travel, the hysteresis coupling allows the motor to spin with the output shaft stationary.

Another major use of hysteresis coupled drives is in air-handling equipment in HVAC systems. Sample parts are shown in Figure 7. In this application the couple is typically made between a bonded ferrite magnet and a ring of iron-chrome-cobalt alloy. The ferrite magnet, usually magnetized with multiple poles on the OD, produces adequate field strength to saturate the iron-chrome- cobalt ring. As the magnet rotates, the magnetized ring follows. When resistance to movement of the output shaft exceeds the breakaway torque, the magnet spins inside the ring, driving each part of the ring through a complete hysteresis loop. In effect, it is a non-contact clutch, operating without mechanical wear or vibration.

When the secondary material in a hysteresis coupled device has adequate coercivity to resist demagnetization, increased torque output is possible. This is useful in pumps as a method to eliminate rotating seals. A cutaway view of a torque coupled pump is shown in Figure 8, courtesy of March Manufacturing. Typical magnets used in these applications include sintered ferrite, injection molded ferrite, injection molded hybrid magnets and sintered NdFeB. The advantage of having no rotating seal is obvious, especially for toxic, hot, chemically reactive or otherwise dangerous materials.

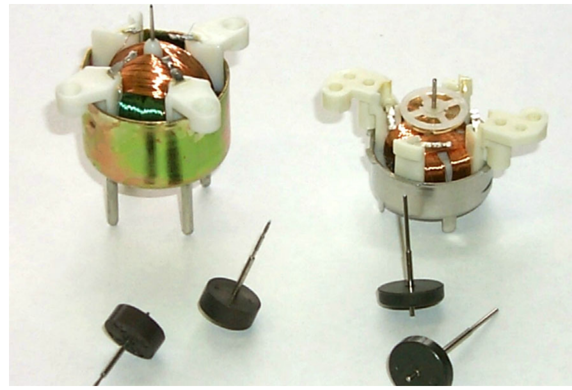

Figure 5
Air Core Gauges
Magnets used in these assemblies are shown in front. The ones on the left are injection molded ferrite; the ones on the right are injection molded NdFeB

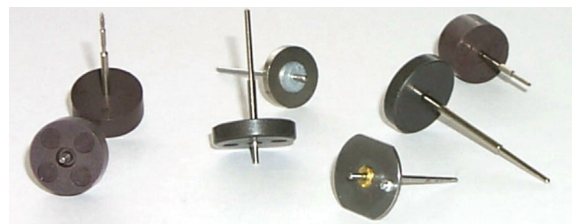

Figure 6
Magnets Used in Air Core Gauges
Materials include injection molded ferrite, injection molded NdFeB, sintered alnico, sintered NdFeB and iron-chrome-cobalt.

Figure 7
Hysteresis Rings and Drive Magnets
The rings are made of iron-chrome-cobalt or similar materials with coercivities of a few hundred oersteds. The Drive magnets are typically an injection molded ferrite.

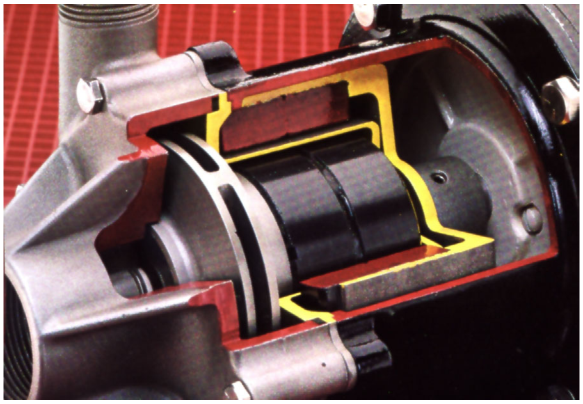

Figure 8
Torque Coupled Pump
The inside magnet set is connected to the pump housing; the outside drive set is fastened to the drive shaft of the motor. A can seal separates the magnets. Photo courtesy of March Manufacturing, Inc.

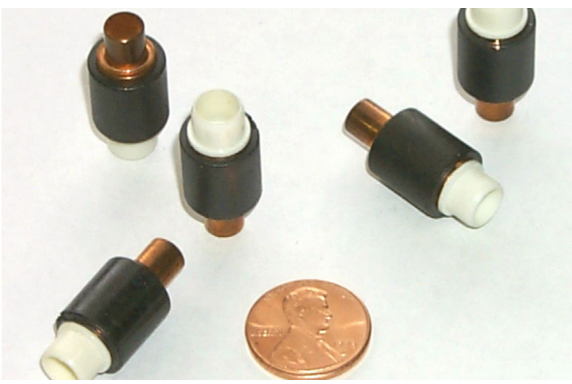

Figure 9
Rotating to Linear Motion Converter
These rotor assemblies consist of a plastic core with internal threads, a brass hub and an injection molded NdFeB outer cylindrical magnet.

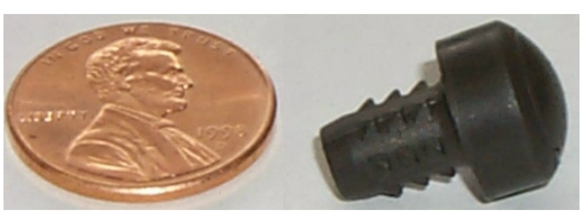

Figure 10
Transmission Chip Collector Magnet

Another interesting application using a rotating magnet is a linear positioner used in automotive applications. The magnet assembly is shown in Figure 9. The core is an injection molded plastic with internal threads which has been molded onto a brass piece. The cylindrical magnet is then molded around this. The unit is magnetized on the OD and secured in the final device so that it becomes a rotor in a motor. The shaft on which it is mounted is threaded. As the rotor turns, the shaft is moved back and forth producing linear motion.

The automotive industry has utilized magnets in many interesting ways. In the transmission of almost every car produced in the U.S. is a magnet, located so as to pull from suspension the fine wear particles. This magnet may be a flat, square sheet of flexible ferrite, a slug fit into the end of a bolt, or one of several other shapes. The example in Figure 10 is an injection molded ferrite magnet which is pressed into a cylindrical hole in a transmission fitting. The material must resist hydraulic fluid and be corrosion resistant.

Cars, trucks, buses and construction vehicles have become more sophisticated. Computers use sensors to monitor temperatures, air and fuel flow, oil pressure, transmission speed, wheel speed (each wheel!), etc. Using these inputs, the computer controls fuel/air ratio, prevents wheels from locking during panic stops, adjusts heating or cooling of the passenger compartment, and much more.

Imagine the damage that could occur if one were to shift a car into reverse while it is speeding forward. In the off-road construction industry, the large (and expensive) vehicles must change gear only under suitable circumstances. To prevent improper operation, a sensor is placed on transmission components indicating which gearing is active. The computer will not allow shifting to take place if the conditions are incorrect.

One such device utilizes an injection molded ferrite disk with selected points magnetized to signal Hall sensors. The example in Figure 11 is an automotive application that prevents improper operation of a FWD transmission. Two injection molded ferrite magnets are formed and magnetized. The two halves are mounted in opposition. The tips of the “fins” of one magnet show through to the back of the other producing very clearly defined poles and precise operation.

Transported goods receive bumps and jarring due to much more than improperly operated transmissions. Not all our highways are smooth nor are truckers infallible. Expensive devices are often shipped in air-ride trucks. Even so, it is necessary to monitor for excessive shock. One device for doing so is a shock sensor. The one shown in Figure 12 is made to be attached to a crate. At least three would be used: one in each orthogonal direction. The small disk shown off-center in the lower left of the device is normally held in position with another magnet structure inside the case. Its inertia will cause it to break away from the other magnet when acceleration is too high. These devices may be calibrated and adjusted providing information on jarring that sensitive equipment received during transport.

Figure 11
Four-Wheel Drive Transmission Position Sensor

Figure 12
Shock Sensor
Small round magnet at lower left has been dislodged from its normal position due to shock.

CONCLUSION

There are many more applications, materials and manufacturing techniques that we have not talked about today. Some of these are: GMR, thin films (sputtered or condensed), roll-forming of malleable magnetic alloys, linear encoder applications, and rotary (non-contact) position sensors. Permanent magnets have become ubiquitous. We are aware of some in our day-to-day lives; many more reside below the level of our consciousness, tucked away in the devices we use: the coffee grinder, the cooling fan in the microwave, focusing magnets on CRT's (television tubes), and the magnet activated reed switch on flip phones.

Have we forgotten the most important permanent magnet of all: Earth itself. Perhaps next time…